

## WE CLAIM:

1 1. Long Elements Method (LEM) for real time physically  
2 based modeling of a deformable medium, comprising the steps  
3 of:

4 providing a plurality of long elements; and  
5 providing a meshing strategy based on said plurality  
6 of long elements wherein number of said plurality of long  
7 elements is proportional to  $n^2$  where  $n$  is length of a side  
8 of said deformable medium thereby substantially reducing  
9 number of time steps required by said modeling.

1 2. The method of claim 1, wherein said deformable medium  
2 represents soft tissue.

1 3. The method of claim 1, wherein said deformable medium  
2 is an object filled with fluid.

1 4. The method of claim 1, wherein said modeling  
2 comprising soft tissue simulation, surgical simulation,  
3 unrestricted multi-modal interactive simulation including  
4 simulating interactive topological changes, volumetric  
5 modeling for homogeneous and non-homogeneous materials, and  
6 graphic and haptic rendering.

1 5. The method of claim 1, further comprising a step of:  
2 providing means for simulating deformations and  
3 dynamics of said deformable medium.

1 6. The method of claim 5, wherein said deformations  
2 include elastic and plastic deformations and said dynamics  
3 include movement of said deformable medium.

7. The method of claim 1, further comprising a step of:  
2 providing means for simulating elastic deformations of said  
3 deformable medium, wherein said deformable medium is an  
4 object filled with fluid.

1 8. The method of claim 7, wherein said means for  
2 simulating is based on a set of static equations, volume  
3 conservation, and Pascal principle  $\Delta P_i = \Delta P_j$  where P is  
4 pressure for any  $i$  and  $j$ .

1 9. The method of claim 8, wherein each of said static  
2 equations is an equilibrium equation defined for each of  
3 said plurality of long elements using material properties  
4 comprising pressure, volume, stress, strain, position, and  
5 velocity.

10. Long Elements Method (LEM) for real time physically  
2 based simulation of a deformable object, comprising the  
3 steps of:  
4 discretising volume of said deformable object with a  
5 plurality of long elements wherein number of said plurality  
6 of long elements is proportional to  $n^2$  where  $n$  is length of  
7 a side of said deformable object;  
8 providing a set of static equations wherein each of  
9 said static equations is defined for each of said plurality  
10 of long elements using dynamic variables; and

11 providing a static stateless deformation engine for  
12 simulating globally and physically consistent elastic  
13 deformations of said deformable object.

1 11. The method of claim 10, wherein said deformation  
2 engine is based on said set of static equations, volume  
3 conservation, and Pascal principle.

1 12. The method of claim 10, wherein said dynamic variables  
2 representing quantities that vary significantly during said  
3 simulation, said dynamic variables comprising pressure,  
4 volume, stress, strain, position, and velocity.

1 13. A system for real time modeling of a deformable object  
2 filled with fluid, said system comprising:

3 means for discretising volume of said deformable  
4 object with a plurality of long elements wherein number of  
5 said plurality of long elements is proportional to  $n^2$  where  
6  $n$  is length of a side of said deformable object;

7 means for providing a set of static equations wherein  
8 each of said static equations is defined for each of said  
9 plurality of long elements using dynamic variables; and

10 means for simulating globally and physically  
11 consistent elastic deformations of said deformable object.

1 14. The system of claim 13, wherein said system is  
2 organized in three main modules comprising:

3 a model definition module for defining geometry and  
4 physics of said deformable object;

5        a simulation module for obtaining deformed shape of  
6        said deformable object; and  
7        a rendering module for enabling user interaction with  
8        said deformable object.

1    15. The system of claim 13, wherein said system is  
2    organized in three decoupled means comprising:  
3        means for simulating deformations of said deformable  
4        object;  
5        means for rendering graphics; and  
6        means for rendering haptics, wherein said decoupled  
7        means are executed concurrently in different processing  
8        means and wherein said decoupled means share a data  
9        structure containing said plurality of long elements.

1    16. The system of claim 13, wherein said system is  
2    implemented in a client-server architecture allowing multi  
3    rendering and multi haptic interactions in a shared virtual  
4    environment.

1    17. The system of claim 13, wherein said system is  
2    implemented in a network environment such that a plurality  
3    of users may simultaneously interact with said modeling.

1    18. The system of claim 17, wherein said network  
2    environment is Windows® NT, Unix, or the Internet.

1    19. The system of claim 13, wherein said system is  
2    implemented in a portable device.

1 20. The system of claim 13, wherein said system is  
2 implemented in a personal computer.

21. Long Elements Method (LEM) for real time physically  
2 based dynamic simulation of a deformable medium, comprising  
3 the steps of:

4 generating a plurality of long elements wherein each  
5 of said plurality of long elements is an one-dimension  
6 entity;

7 meshing said deformable medium based on said plurality  
8 of long elements wherein number of said plurality of long  
9 elements is proportional to  $n^2$  where  $n$  is length of a side  
10 of said deformable medium; and

11 simulating said deformable medium in at least two  
12 different dimensional spaces simultaneously, wherein said  
13 at least two different dimensional spaces comprising lower  
14 order dimensions and higher order dimensions.

1 22. The method of claim 21, wherein said meshing step  
2 further comprising the steps of:

3 projecting said deformable medium into a plurality of  
4 representations in lower order dimensions; and

5 crossing said deformable medium with a plurality of  
6 reference planes of lower order dimensions, wherein points  
7 inside said deformable medium are simulated with respect to  
8 relative positions on said reference planes.

1 23. The method of claim 21, wherein said plurality of long  
2 elements comprising straight long elements and free form  
3 long elements.

1 24. The method of claim 21, wherein said at least two  
2 different dimensional spaces comprising a one-dimension  
3 long element space and a three-dimension Cartesian space.

1 25. A system for real time physically based dynamic  
2 simulation of a deformable medium utilizing Long Elements  
3 Method (LEM), comprising the steps of:

4 means for generating a plurality of long elements  
5 wherein each of said plurality of long elements is an one-  
6 dimension entity;

7 means for meshing said deformable medium based on said  
8 plurality of long elements wherein number of said plurality  
9 of long elements is proportional to  $n^2$  where  $n$  is length of  
10 a side of said deformable medium; and

11 means for simulating said deformable medium in at  
12 least two different dimensional spaces simultaneously,  
13 wherein said at least two different dimensional spaces  
14 comprising lower order dimensions and higher order  
15 dimensions

1 26. The system of claim 25, wherein said means for  
2 simulating further comprising a deformation engine for  
3 simulating stateless deformations of said deformable medium  
4 and a dynamic simulation computing means for providing  
5 state-based dynamic simulation and for integrating said  
6 stateless deformations and said state-based dynamic  
7 simulation, said computing means deriving three-dimension  
8 shape of said deformable medium from configuration of said  
9 plurality of one-dimension long elements.

1 27. The system of claim 25, wherein said at least two  
2 different dimensional spaces comprising a one-dimension  
3 long element space and a three-dimension Cartesian space.

1 28. The system of claim 25, wherein said plurality of long  
2 elements comprising straight long elements and free form  
3 long elements.

1 29. The system of claim 25, wherein said meshing means  
2 further comprising:

3 means for projecting said deformable medium into a  
4 plurality of representations in lower order dimensions; and

5 means for generating a plurality of reference planes  
6 of lower order dimensions, wherein said plurality of  
7 reference planes crossing said deformable medium providing  
8 reference points and wherein points inside said deformable  
9 medium are simulated with respect to relative positions on  
10 said reference planes.

1 30. The system of claim 25, wherein each of said plurality  
2 of long elements comprising a combination of two mass-less  
3 long elements attached to a particle of known mass.

1 31. The system of claim 25, wherein said system is  
2 implemented in a network environment such that a plurality  
3 of users may simultaneously interact with said simulation.

1 32. The system of claim 31, wherein said network  
2 environment is Windows® NT, Unix, or the Internet.

1 33. The system of claim 25, wherein said system is  
2 implemented in a portable device.

1 34. The system of claim 25, wherein said system is  
2 implemented in a personal computer.

1 35. The system of claim 25, wherein said system is  
2 implemented in a surgical interface.

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